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Embryos, microscopes, and society

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ABSTRACT

Embryos have different meanings for different people and in different contexts. Seen under the microscope, the biological embryo starts out as one cell and then becomes a bunch of cells. Gradually these divide and differentiate to make up the embryo, which in humans becomes a fetus at eight weeks, and then eventually a baby. At least, that happens in those cases that carry through normally and successfully. Yet a popular public perception imagines the embryo as already a little person in the very earliest stages of development, as if it were predictably to become an adult. In actuality, cells can combine, pull apart, and recombine in a variety of ways and still produce embryos, whereas most embryos never develop into adults at all. Biological embryos and popular imaginations of embryos diverge. This paper looks at some of the historical reasons for and social implications of that divergence.

This essay takes embryos as its subject, and human embryos in particular. An assumption in understanding human embryos holds that they are very much like embryos in closely related organisms, and that we can therefore learn about humans by studying other animal embryos. The "media" to be explored, therefore, includes the embryos of humans and other animals, and also interpretations of those embryos. The "instruments" include imagination, observation, and experimentation, with quite different results in each case. In fact, study of embryos as they appear in society reveals distinct understandings that reflect underlying divergent interpretations of life.

Although there are various versions within each of these understandings, discussion here will look at one cluster of ideas representing the public embryo, and at a different cluster of ideas representing biological embryos. These two ideas about embryos are not the same, nor are they even obviously converging, so it is worth examining the reasons for the differences and relationships while being clear about each understanding in itself. These ideas receive much more extensive presentation in a larger context with a different focus in my *Embryos Under The Microscope: Diverging Meanings of Life* published with Harvard University Press, 2014. I benefitted from discussions of the ideas at York University in the seminar series organized by Joan Steigerwald, which forms the basis of this set of essays. She urged participants to write these as essays, pointing liberally to other published works of our own, which I have done. More detail and additional references reside in those longer works, as well as in those of others whose contributions are only mentioned here.

1. Public embryos

By public embryos, I mean those that exist in the public and political arenas. Of course there are public leaders who embrace biological understandings as well, but the publicly imagined embryo is the one most often invoked in public and policy discussions. This embryo seems familiar. It starts as an egg cell that undergoes "conception" as it is fertilized and becomes the very first stages of an individual's life. This is largely an imagined rather than an observed embryo. Then the embryo becomes implanted into a woman's uterus and begins to grow and undergo differentiation, and at this point it becomes even more an imagined entity since it

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cannot be directly observed. In our imagination this is all a continuous process that defines the life of an individual human.

Indeed, this description is biologically accurate as well—to a point and at a general level. We'll get to the differences in the next section. At this point, this public understanding of the embryo is not directly in opposition to our scientific knowledge. But it adds a great deal of imagination to the biological facts we know. And it is those imagined properties that matter in public discussions; we imagine that the embryo is alive, a "life" that is essentially the same at all developmental stages. In this case, we might be tempted to invoke claims about the meaning at all developmental stages of the embryo that go beyond what we can see and what we can know. We might, for example, invoke something like the "personhood" movement does. Supporters of this movement argue that the embryo starting at fertilization has personhood and deserves the same rights and protections of any other person (For example, see the websites for personhoodusa.com, personhood.net, and those of other related organizations with similar names.). The Catholic Church and many others share the assumption that with fertilization, or conception, comes personhood.

This is not the place for a philosophical or political discussion about personhood, though there are certainly many things to say about that subject. It is, however, the place to acknowledge that this publicly imagined embryo-as-little-person exists in the public arena. As we will see, this public version is importantly different from the understanding of an embryo we get from putting it under the microscope and watching it carefully as it unfolds and changes during a series of developmental stages.

For most of history, some people cared about embryos but they were not of central importance politically or culturally. Pregnancy, reproduction, and babies were important, but the process leading to them remained largely in the background. That changed for a number of reasons in the later twentieth century. Human embryonic stem cell research, first publicly announced in 1998, caused some of the most widely discussed and complicated debates about embryos, with newspaper and television images widely distributed. The public experienced heated debate about stem cells, cloning, and embryos as a result of scientific innovation, and embryos became a more public object than they had been. The scientific ability to work with human embryonic stem cells raised new questions about how we understand embryos and their social as well as scientific importance.

The resulting discussions depended on a simplified and often distorted public imagination of what an embryo is, despite efforts by serious news media and scholars to explain the biological intricacies. To many, it seemed a question of whether to take human embryos at the stage just before they become implanted into a uterus and to kill them in order to harvest the pluripotent stem cells inside. This meant fertilizing eggs and allowing them to divide in vitro, in glass dishes. It meant fertilizing a number of eggs and hoping that some would develop, and it meant being able to watch them divide from one cell into more and more, up to a couple hundred cells that make up the late blastocyst stage.

For some, the embryos in their earliest stages are already tiny persons. They are not quite like the older imagined homunculus invoked by Nicolas Hartsoeker and others, which was thought to be an actual tiny man or woman already formed inside a spermatozoon or perhaps inside an ovum (See discussion, Maienschein, 2003, pp. 26–29.). Rather, they are continuous with and simply the earliest stages of an individual human and therefore seem to have some special status as a sort of little person. To kill them therefore seems morally wrong to the strongest proponents of this view. Even to those who are less sure about the moral status, destroying these tiny embryos by choice makes them feel queasy.

A background consideration that has undoubtedly influenced the way people envision embryos comes from the international popularity of Swedish photographer and journalist Lennart Nilsson's work. Nilsson's fascination with microscopes and cameras led him to explore what could be seen with the medical approach, laparoscopy and then further what he could do using an endoscope to capture images from inside pregnant women. His first images actually depicted dead fetuses, but were so beautifully composed that they seemed to present the very essence of life. In 1965 he published *A Child is Born* and in the same year his images graced the cover of the widely read *Life* magazine. Nilsson's images appeared everywhere, and they shaped or probably more nearly reinforced the public perception of how humans develop. What were mostly fully formed later stage fetuses were often referred to in the media as "embryos," though Nilsson never sought to deceive about their nature or their status. These images, whether of dead or live specimens, seemed to present little people resting peacefully and waiting to be born. His documentaries such as *The Miracle of Life* in 1983 reinforced the impression (Nilsson, 1967, 1983).

Yet as public discussion about stem cell research has made clear, the fact is that ever since we have been able to carry out in vitro fertilization for fertility treatments, we have been destroying tiny embryos. (See the American Society for Reproductive Medicine website for more information about IVF clinics and policies.) Lots of them. On purpose. And without worrying about them very much. In fertility clinics, people provide eggs or sperm, sperm fertilize eggs, and embryos result. There are too many embryos to be implanted into a prospective mother. Some are frozen, others discarded. Many would never continue to develop further anyway, for a variety of biological and medical reasons. Again, this is routine standard of care for embryos, as it were. The difference with embryonic stem cell research is simply that the embryos are actually used, in this case to harvest pluripotent cells and to culture them for possible research or therapeutic use.

Why did stem cell research ignite such a firestorm of controversy, then? If the fertility business had been generating and destroying embryos for decades, why would stem cell research be any different? Did the goal of actually putting the cells to use, as well as fulfilling the hopes for treating infertility in those who could afford to pay for the rather expensive process justify the means of embryo destruction? For some, yes. For others, no. In part this was because a mix of opinions already existed, but the fertility business had remained largely unregulated, undiscussed, and completely unfamiliar to most Americans in particular. Embryonic stem cell research brought the destruction of embryos into the public sphere and in fact made the embryo public in a way it had not been before.

With the embryo out in the open, in effect, advocates of various political positions could imagine the embryo in various ways and assign their preferred meanings to it. Anti-abortionists invoked an image of the embryo as if it were the equivalent of a late stage fetus or even of an infant, as we have seen (and websites at the time even featured many such fetuses labeled as embryos, with the suggestion that stem cell research would involve killing such humans). Those opposed to fertility research and treatments could incant, only more loudly than before perhaps, that embryos are persons and deserve protection. Those in favor of abortion rights and/or embryo research continued to maintain that the early embryonic stages are in fact not yet persons and do not deserve to be treated or imagined as such.

All such debates have taken place in the context of reproduction politics and preferences (For example, see Franklin, 2007 and Thompson, 2007, 2014.). We see a wide diversity of competing opinions about several different overlapping and intersecting issues, which leads to lively discussion but considerable lack of clarity at times. Many feminists have worried about the abuse of

women involved in the process of procuring eggs, while others have worried that attacks on stem cell research would lead to restrictive responses limiting women's rights and access to fertility treatments. Some who saw embryos as having "special" status, as President George W. Bush put it, for example, worried that researchers should not do any and all kinds of research they might want to with embryos, but that the argument for using those that had already been destroyed could be morally justified.

This latter position is the one Bush adopted in his address on August 7, 2001. He spoke from his ranch in Texas and announced that he was fulfilling his promise to provide executive guidance on stem cell research. In a nuanced position, which he reported was guided by the National Institutes of Health Stem Cell Primer (later renamed as the Stem Cell Basics), Bush presented his executive order that allowed federal funding for research on those cell lines that already existed at the very moment he began his speech (NIH, 2001). In other words, if the embryos had already been destroyed in order to produce the cell lines, then more was to be gained by allowing research on them. But destruction of any additional embryos was prohibited. Bush argued that he had been persuaded that approach would protect all future embryos while also allowing research to go forward. He believed that the existing cell lines would provide sufficient research material to proceed with attempts to develop cures (Bush, 2006).

Critics attacked immediately. While some had wanted him to ban all federal funding for all research, including on existing cell lines, others had wanted him to allow further research. Almost everybody found something to complain about. But not for long, since a month later on September 11, 2001 terrorists attacked the World Trade Center and The Pentagon, and attention swiveled away from embryos. Of course, debate did continue, but the force of public opinion was blunted for some time. It peaked again when California's Proposition 71 explicitly provided funding for stem cell research, including on human embryonic cells, and with news of a series of apparent scientific breakthroughs, proposed clinical trials, and various other news reports.

Many people have said many things about the California stem cell initiative but Charis Thompson's *Good Science: The Ethical Choreography of Stem Cell Research* nonetheless sheds new light on the subject. She argues that in order to get to "good science" we need a "choreography" of science and ethics. The biopolitics of stem cell research has made it particularly difficult to sort out the range of issues and opinions on all sides; all the more reason then for an effective choreography of the dance. Now that stem cell research has matured, or in her sense reached the "end of the beginning" of the stem cell enterprise, it is time to pay closer attention to what should count as good science. Such science must involve doing good ethically, and also doing well socio-economically while doing science effectively. Her essays that make up the chapters of her book walk through issues of politics, policy, ethics from multiple perspectives, and the constraints of social and economic reality. "Good science cannot be achieved or legislated once and for all," she notes. "It is ongoing and iterative, and it requires openness to dissent and the best work of many different kinds of contributors" (Thompson, 2014, p. 225).

Sarah Franklin provides another perspective with her *Biological Relatives: IVF, Stem Cells, and the Future of Kinship.* Franklin discusses ways in which the biological and social intermix. With its focus on the United Kingdom, Franklin's study is an excellent complement to Thompson's focus on California and my own on the United States. The U.K. has been much more publicly reflective about reproductive technologies such as in vitro fertilization and all its complex permutations, as well as about embryo research more generally (Franklin, 2013).

The point here is not to repeat all the discussions of stem cell and related embryo research. The two books just mentioned do a fine job of covering a wide range of important topics in very recent terms. My main goal is to suggest that it was stem cell research carried out in the context of reproduction that made embryos more public, more visible in an imagined sense, and more contested. Stem cell research brought questions about embryos to the legislative, judicial, and executive branches of government in the United States and elsewhere. The research and its possibilities, and the apparent necessary killing of embryos elicited thoughtful responses from the National Institutes of Health and the National Research Council in the United States and from other bodies in other countries (NIH, 2011; NRC, 2001, 2002). Stem cell research did this in a way that in vitro fertilization had not quite done. The result has been a very strongly imagined embryo with public resonance. And that is very different from the biological embryo in a number of important ways. I am not claiming that the two are in conflict, or that they could not be compatible, but rather that the arguments have been divergent and the voices discordant.

2. Biological embryos

In contrast with public embryos, biological embryos are understood to start with one material cell that has some structure but very little gene expression, that then divides into two cells, then four, then eight, and then more and more. At this point, the embryo is just a bunch of cells that are beginning to divide and differentiate, and eventually develop into something with the structure and function of a complex organism. The embryo changes gradually over time, and eventually what started as one cell may be successful in becoming a fully formed adult of the right sort. Biological embryos go through developmental stages that differ from one another and that demonstrate progressive differentiation and growth.

The primary difference between this biological embryo and the publicly imagined one is that this is "just" biological material without structure and with very little function until later stages. There is very little differentiation at the early stages, and in humans the first eight cells each remain totipotent. That is, each of them has the capacity to become a whole organism. At this point, they are all alike. This is what makes it possible to have identical twins, for example, or quadruplets or even more, because the cells divide and then separate rather than stay together in one whole organism. Cells retain this capacity and remain totipotent up until the eight-cell stage. At that point, they begin to divide at different rates, and to differentiate into a cluster of cells surrounded by a layer of cells that becomes the placenta. The cluster of cells in the middle is called the inner cell mass, and they lose their capacity to become the entire organism and become instead pluripotent. That is, each individual cell can become any kind of cell, but no one cell can become all kinds.

In short, this biological embryo in its earliest stage is a bunch of cells. It is not organized yet, it is not expressing genes that cause differentiation, and up until what is called the blastocyst stage, it does not even grow larger. It is just a bunch of material cells that interact and interconnect. Its "meaning" is quite different from the newly conceived public embryo with its imagined emerging personhood that has evoked calls for protection.

In each case, we know that the very beginning changes lead through time to the fully formed infant that may result. But in one case, the public imagines the infant as "in" the egg in some way, even though not literally. In contrast, the biological understanding acknowledges that most fertilized eggs never become infants at all for a large number of reasons and that the characteristics that make up the individual emerge only very gradually, over time and with

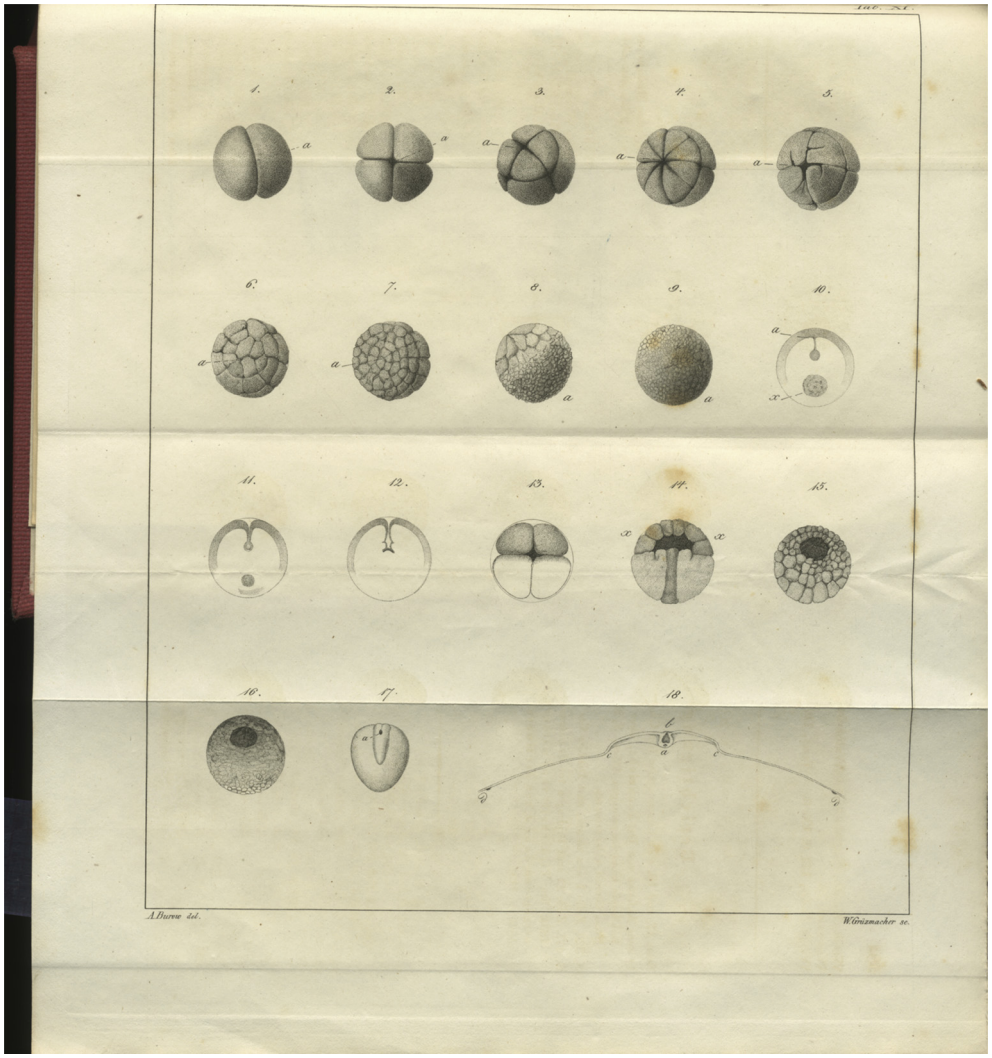

Fig. 1. Karl Ernst von Baer's segmenting development of frog eggs. From von Baer, "Die Metamophose des Eies der Batrachier vor der Erscheinung des Embryo," *Archiv für Anatomie, Physiologie und Wissenschaftliche Medizin* (1834: pp. 481–509). Plate labeled as Table XI and bound at the back of the volume. Courtesy of the Marine Biological Laboratory Library.

the input of many environmental factors. In the egg is just an egg. For more detail on the intricate processes of embryo development in humans, see especially the marvelous *Life Unfolding: How the Human Body Creates Itself* by anatomist Jamie Davies. He shows step by step the astonishingly well-choreographed biological processes that allow the cells to self-organize into an embryo and eventually into a person (Davies, 2014).

Thus, we have two different and divergent ideas of embryos. Most importantly, history shows us that both have existed for a very long time. It is only recently that the two have begun to collide more often and more vigorously as the biological embryo has become more public, and as advocates have attempted to move the public embryo into discussions of policy in ways for which it matters whether they have the story "right." That is, only recently have the biological and public embryos begun to occupy the same political spheres. It is worth reflecting on the historical episodes that have brought us to this point.

3. Historical emergence of understanding embryos

Throughout history and continuing today, the public embryo has focused on imagining the continuities from one stage of development to the next and so on. Yet early Jewish and Catholic interpretations, and Muslim interpretations that followed, placed the beginning of an individual life as beginning at a point of discontinuity. That was the moment of quickening, ensoulment, or hominization as it was variously called; scholars as well as the public imagined that fluids from the mother and father came together in some way and combined, such that at "forty days" the fluids became an individual. Different interpreters assigned full "personhood" with legal consequences at different stages of development thereafter, in some cultures not until well after birth. Aristotle held a similar view, though it was not some religious ensoulment but rather action of his final cause that led the combined fluids to emerge gradually and epigenetically as an individual organism (See discussion in Maienschein, 2014, chap. 2.).

By the early nineteenth century, Karl Ernst von Baer had been busily working to understand chick development, to find a mammalian egg, and to trace the stages of frog development. His illustrations in a paper from 1834 showed clearly how gradually the form emerged from the fertilized egg and how very unformed the earliest stages remained. There he offered an illustration of a frog embryo, showing that it started as an egg cell that divided and kept dividing until it began to take on some form. He watched the

process and recorded the details to sort out what actually happens rather than what theory might suggest (Von Baer, 1834) (see Fig. 1).

Despite such accumulating biological evidence that fertilization is just the very first stage in a complex process of development, the Catholic church declared formally that the individual's "life" and its individuality start at "conception" rather than at any later point. In 1869 Pope Pius IX declared this to be so, during the period called Vatican 1 or the First Vatican Council, which involved a conservative reform. His declaration provided a basis for insisting that abortion, contraception, and other interferences with the biological process are morally illicit for Catholics (Maienschein, 2003, pp. 42–43). This was a change from previous views, and much has been written about this elsewhere.

The point here is that for millennia the public understanding of embryos had placed an imagined beginning for each individual organism at the time of ensoulment, or forty days. By the middle of the nineteenth century, however, while biologists were observing many details about the series of developmental stages that brought very gradual emergence of form, for Catholics life suddenly was seen as starting at conception. These two public ideas of an embryo have persisted, but for at least the last quarter of the twentieth century the life-begins-at-conception image has gained considerable public dominance. This image has been reinforced by a variety of religious and philosophical advocates.

In fact, this public embryo does not contradict biological understanding — to a point. Of course there is a beginning point with fertilization. The difference between the publicly imagined and biologically studied embryos is in the meaning assigned to fertilization and to the earliest developmental stages. For the publicly imagined embryo, the beginning is the same as later stages in important ways; for biologists, each stage is very different.

It is worth looking briefly at the accumulating knowledge biologists have been adding to the biological understanding of embryos, an increasingly different understanding but one that has until recently co-existed with the imagined embryo. By the seventeenth and eighteenth centuries, observers had begun to peer through microscopes and to see blobs of unformed cells. By the mid-nineteenth century other observers watched sperm cells fertilize egg cells and begin cell division. They saw this in a number of different species, though not humans. By the early twentieth century, biologists understood a great deal about the development of many organisms, especially invertebrates such as sea urchins, as well as frogs and chicks. Only gradually during the twentieth century did they gain more directly observed knowledge about mammals, however, since mammalian eggs are inside females and therefore not visible (For more detail, see Maienschein, 2014a, chaps. 2 and 3.).

In 1978, in vitro fertilization brought the egg, the fertilization process, and therefore the early embryo out into the open. This is the first time the publicly imagined and envisioned embryo began to collide directly with the biologically observed embryo. The image of the embryo in the dish and the resulting "test tube baby" excited the public imagination in new ways about what was possible with human reproduction. Yet the publicly imagined embryo remained that of the beginnings of a person there in the dish (For more discussion, see Maienschein, 2014a, chap. 5.).

And, yes again, there are cells in the in vitro culture dish. And, yes again, those cells are continuous with the resulting individual. But that's only in those few cases that actually result in fertilization and all the complex additional steps it takes to make an infant. In vitro fertilization starts with eggs, which have to be procured from women at some considerable cost to those women (For example, see Thompson, 2014 and Franklin, 2007.). Then sperm, which is acquired from men as designated donors or through sperm banks, is added. In a minority of cases, a sperm cell fertilizes an egg cell and forms a zygote. At this point, the chromosomes go through a complex dance to make sure that the resulting "conceptus" ends up with the right number of the right type of chromosomes. This pre-implantation embryo can exist in the dish up until the blastocyst stage, when there are an estimated 200–300 cells. At this point, the blastocyst has to be transplanted into a uterus in order to survive and continue development.

We can watch this process take place up to the point of implantation. Quite a number of fertilization videos showing what happens appear on YouTube and on education websites. Clearly, this is a bunch of cells. If the camera shows the action, generally it is clear that most eggs never become fertilized. And most of those that are fertilized never progress to the late blastocyst stage, and of those most are never implanted. Fertility clinics have improved their success rates in the past by implanting more than one embryo and hoping that only one will continue to develop. More recently, many clinics have focused technologies on obtaining the very healthiest embryo and then transplanting just one into the uterus to increase the odds of a healthy pregnancy. (See, for example, American Society for Reproductive Medicine for protocols and procedures.)

These early embryos are visible in the clinic dish. A few of them will go on to become implanted embryos, and a few of those will continue to become successful healthy infants. Most will not. This is part of the biological understanding of embryos. Again, the earliest stages are just a bunch of cells. They are material, they follow processes of cell division, and they change over time. But they are not yet formed, nor do they have very complex functioning or much gene expression yet. Most just die. Any romantic notion of each fertilized egg as an individual person that deserves legal protections or has a very special status simply does not match well with the reality that most die. The biological embryo and the imagined public embryo are at odds in the sense of the meanings assigned to each. For the first few decades of IVF, the fertility business had very strong incentives to do their work quietly and not make the embryo very public. In recent decades, the public and biological ideas have had reason to collide in ways that are only likely to increase in number.

4. New science, new public understanding, and new collisions of meanings

For practical reasons, in vitro fertilization had reached a truce with public imaginations about what those embryos in a dish might be. Many people with fertility problems wanted help, and the momentum lay in developing better technologies rather than in restricting applications. Cloning and stem cell research changed the political landscape for embryos.

Cloning involves transplanting a nucleus from one cell to another cell from which the nucleus has been removed. For reproductive cloning, the host cell is an egg, and the resulting embryo would be considered a clone of the donor from which the nucleus came. For so-called therapeutic cloning, the developmental process would stop at the blastocyst stage and the pluripotent stem cells would be harvested rather than implanting that blastocyst into a uterus. The reason for carrying out such a process would be to produce stem cells that are genetically like the donor.

Stem cell research attracted such lively public attention, I'm sure we all recall, because the process of obtaining the pluripotent stem cells requires harvesting them from an embryo. And the "harvesting" effectively kills the embryo. The technology of human embryonic stem cell research first published in 1998 therefore made clear that embryos could be put to use—initially for research purposes and then in newly imagined ways through stem cell

therapies. The case of embryonic stem cells has been discussed, so we need not cover that ground again here.

But imagination about what might be possible created a modified meaning for the public embryo. For many, the discussion reinforced existing impressions of the embryo as a special kind of thing that is almost, or potentially, or perhaps even already a person. Others imagined the uses for pluripotent stem cells and saw a higher good. Still others looked more closely at the biological embryo and realized that cells in a dish during early stages of embryonic development are just cells. Public imaginations about embryos did not change significantly, but they became more vivid, more immediate, and more real as this discussion came directly into the political arena. Much has been written about the legislative, judicial, and executive branch actions and reactions, so we need not repeat those discussions here. Fewer scholars have looked carefully at state decisions, however, so that remains an open area. (The National Council of State Legislatures website provides a useful guide to U.S. legislation, for example.)

5. Embryos that aren't what they are supposed to be

For many centuries, people have been fascinated by what were called "Siamese twins," named for the reported origin of early cases and consisting of two bodies conjoined in some way. Some are joined superficially at a hip or the chest, and otherwise consist of complete bodies. Others are joined more deeply and share organs or even heads. The more complicated the connections, the less likely the combination is to live long. Today, in developed countries surgery can address many cases and the most common standard of care calls for separating the two or sometimes having to kill one to save the other (see Fig. 2).

In other cases, two embryos come together and develop abnormally. In some cases, one twin dies and is absorbed by the other. Yet in other cases, the second twin is not absorbed; rather one continues to develop apparently normally, but with a developing parasitic twin inside. Examples include an individual with the back of another individual growing out of it, or with part of a body curled up inside the living individual. All manner of possibilities seem to occur. Again, today in developed countries, surgery can correct what is seen as a medical problem, but cases still do arise if there is no early medical intervention. They show that the individual organism has the capacity to absorb, combine with, or otherwise change another organism. This fact, in turn, calls into question simplistic assumptions about what counts as an individual. (See Maienschein, 2014b, for discussion and for considerable public response.)

Fig. 3. Beatrice Mintz and her chimeric mice. (Photo available through the Smithsonian Institution, Acc. 90–105—Science Service Records, 1920s–1970s, Smithsonian Institution Archives, http://www.flickr.com/photos/smithsonian/6891505741/.)

Still a different kind of pathology that may seem similar but actually is not concerns teratomas. The cases just described consist of two separate, and at some point independent, fertilized eggs that come together. In the case of teratomas the embryo is single, yet

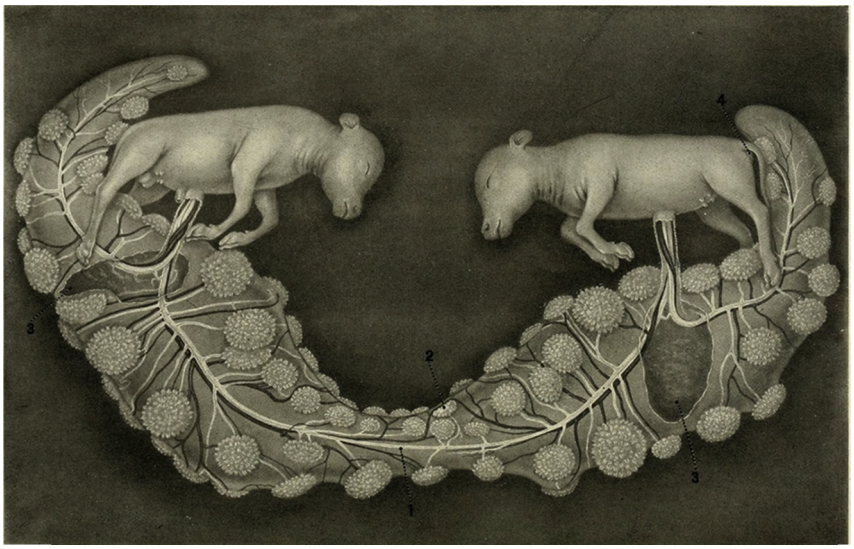

Fig. 2. Frank Rattray Lillie's freemartin, with one male and one female twin joined, as part of Lillie's demonstration of the ways that the male dominates the female's development. This is the original drawing, hanging in the Marine Biological Laboratory Archives and donated by Lillie.

some of the pluripotent stem cells inside the blastocyst seem not to develop at the time they normally would. They remain pluripotent and keep dividing. Then at some point, they begin to differentiate into tissues that would not normally exist in the location and time they appear. For example, in work that led him to identify and name pluripotent stem cells, Leroy Stevens reported the appearance of teratomas in a certain strain of mice and discovered that hair, teeth, and other tissues formed inside the testicles. He later showed that he could graft cells from that cell line to another mouse and produce teratomas after transplantation (Lewis, 2000; Stevens, 1970). Small teratomas probably go unnoticed quite often, so it is not clear just how common such developments are.

These are all examples of how individual embryos are not quite as neatly defined as the public perception would suggest. Other examples show even more dramatically just how complex embryonic development is. Chimeras occur when cells of two different germ lines join together in one individual. We know now that this happens frequently in mothers, who absorb some cells from their offspring. Other more routine examples occur when medical procedures involve transplanting cells from one organism to another—whether as tissue, organs, or blood. The result is technically a chimera. Those examples do not raise the kinds of questions that embryo chimeras do, however. As Beatrice Mintz and Nicole Le Douarin showed in the 1960s and 1980s respectively, it is possible that two embryos from different species can actually merge completely and develop into apparently perfectly healthy organisms. Mintz showed this by combining embryos from two different strains of mice, and Le Douarin showed it with chick and quail and embryos of other species (Le Douarin and McClaren, 1984; Mintz, 1962) (see Fig. 3).

But what is an embryo if it is possible to take cells from different organisms and even different species and combine them to construct a new kind of result? What is a human embryo if researchers could take a human embryo and that of another species and combine them to grow into a new kind of organism? Nobody has done such an experiment, or not successfully and not to our knowledge, nor is it likely to succeed easily. But the very possibility raises deep questions about what an embryo actually is along with the obvious ethical questions. Such chimeras or combined twins do not fit the public perception of embryos. Biologically, these phenomena are not obvious, but they fit with our historically growing understanding of embryos and how they develop.

Embryos with three parents (in the sense of three contributors to the genome of the offspring) raise different kinds of questions for the public perception. Most recently, researchers have learned how to add mitochondria from a donor to an egg that lacks healthy mitochondria of its own. Because the mitochondria bring different genetic material, this procedure produces a new kind of chimera and raises new ethical questions about the safety as well as the identity of the offspring. The fact that the procedure is possible and can be done effectively shows in still other ways how our public understanding of embryos is lacking.

Synthetic biology stretches the imagination still further. As Craig Venter and his team showed, it is possible to use a scaffold to synthesize parts of a cell. Venter wants to go all the way and synthesize a cell from "scratch." Venter and extremely creative researchers and engineers like him would surely love to synthesize an embryo if they could. How exciting it would be to engineer life at that level and in that way! And how horrifying that prospect would be for many. New technologies and synthetic biology seem to raise new questions and redraw the battle lines in ways that discovery of new knowledge has not yet done (Forum on Synthetic Biology, 2014).

The publicly imagined embryo is very limited, and while some are excited by all this innovation, many find it frightening to envision something quite different than their cherished assumptions have led them to believe. Accumulating knowledge about conjoined or parasitic twins, teratomas, chimeras, and other scientific discoveries that show just how complex the biological embryo really is has elicited some interest but has not yet commanded significant public attention or a new social understanding of embryos. The mantra that life begins at conception, or fertilization, gives a tidy understanding in which it is relatively easy to assign meaning and value to the various developmental stages. As a diverse public, we may argue about whether the earliest embryonic stages deserve the same legal protections or have the same rights as later stages. We may have different feelings and convictions about the precise moment when an embryo becomes a person. But we know that many people believe that moment is at conception. The battle lines about values seem relatively clear, and the debates about abortion have persisted in the public arena for a very long time.

6. Why bridging the gap is so hard, and why it matters when situating science in society

In fact, embryos are very much more interesting, creative, and resilient than the standard public impression would suggest. The capacity to regulate the whole in response to changing environmental conditions shows that embryos can be very robust and are much more complex than the simple idea that life begins at conception and just grows up. The biological realities of embryos show how limited the public imagination has been.

So, as biological knowledge accumulates, and our biological understanding of the embryo diverges yet further from the publicly imagined embryo, why does the public embryo not change? Why do the two not converge so that the public imagination embraces the complexities of biological reality?

The easy answer is politics. Just as we, perhaps especially in the United States, seem to diverge further on many social issues rather than reaching a middle ground of understanding, people seem committed to their long and deeply held views. There is little incentive to change one's treasured convictions in part because we have accepted a disconnection between science and society. The popular science writer and paleontologist Stephen Jay Gould maintained that science and social views and values exist in two non-overlapping magisteria (Gould, 1999). He was referring to issues about evolution in particular, but the same reasoning holds when thinking about embryos and abortion. Gould and many others hold that it is possible to have cherished beliefs that conflict in some ways with scientific ideas, and that's ok.

I disagree. In some cases where scientific and social views conflict, it is possible to hold on to aspects of both. But in other cases, the conflicts become too important to ignore or gloss over. When it is time to make social policy, it is not reasonable to reject the scientific knowledge and pretend that it does not exist. It is not reasonable to develop social policy that is in direct conflict with biological knowledge. Though science should not by itself determine social values and policies, those policies should at the very least not be inconsistent with the science.

Considerable discussion of the public will to reject science, or in some cases willfully deny scientific claims has led to widely discussed work about climate change, smoking, and we can add embryo research. Robert Proctor and Londa Schiebinger have invoked the name "agnatology" for the cultural production of ignorance. In a conference convened by the British Society for the History of Science, they led discussion of how public ignorance is produced and reinforced (Proctor and Schiebinger, 2008). Proctor's own work has focused on smoking. Naomi Oreskes and Erik Conway have looked at the relations of smoking and climate change, showing an intentional campaign to create doubt about well-established scientific knowledge (Oreskes & Conway, 2010). Evolution provides

another example. And now embryo research. With all these authors, I want to reject the legitimacy of such an approach and demand that at the minimum, public policy in our secular society should not be inconsistent with established scientific knowledge.

This means that any public that might decide that embryos should be treated as persons with full legal rights, as the personhood movement suggests, has to understand that most embryos die naturally and many more die in the process of fertility treatments. Any public that might decide to define an embryo as an individual will have to recognize that it could, in fact, divide into two individuals or could absorb another. Any public seeking to protect the germ line of individuals would have to understand that germ lines are modified by a variety of chimeric activities.

7. Conclusions

Using the instruments of biological sciences to probe embryonic media provides an intriguing case study of science in society. This is a case of diverging meanings of embryos, and also of life. It is a case of conflicting values underlying the preference for a publicly imagined embryo or a biologically observed embryo. We cannot dictate what policy will or even should emerge from such conflicts. But we can seek to inform the process by bringing the biological understanding, accessible with microscopes and careful observation and experimentation, to the public discussions as well as acknowledging the depth and persistence of the social commitment to the public embryo.

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